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Diamond Light Source Proceedings / Volume 1 / Issue MEDSI-6 / October 2011 / e52
DOI: 10.1017/S204482011000078X, Published online: 05 January 2011

Diamond Light Source Proceedings, Vol 1, e52, page 1 of 5

MEDSI-6 2010
doi:10.1017/S204482011000078X

Poster paper

Support structure design of Quantum Material Spectroscopy Center beamline insertion devices

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(Received 14 June 2010; revised 7 October 2010; accepted 4 November 2010)

A high-energy elliptically polarizing undulator (EPU) and a low-energy EPU are designed to share a single C style supporting structure. Each of the EPUs is 4 m in length. Finite-element analyses (FEA) are performed to choose the proper girder style and section size and to verify the components' strength and deflection. The most difficult challenges are the huge three dimensional magnetic forces on high-energy EPU and the space limitation for the two EPUs. In total the whole structure has 18 ball screw drive systems. A total of 30 sets of linear bearings are used in the structure.

1. Introduction

The Canadian Light Source (CLS) is constructing a new phase III beamline – Quantum Material Spectroscopy Center (QMSC) at the 09ID location. QMSC is designed to cover the energy from VUV radiation to soft X-ray (15–1000 eV) with arbitrary polarized light. Two APPLE II type quasi-periodic undulators are designed to fulfil this energy range. The low-energy elliptically polarizing undulator (EPU) covers photon energy approximately 15–200 eV while the high-energy EPU covers photon energy 200–1000 eV. An existing adjacent bend magnet beamline limits the support structure to be a C style frame.

The mechanical parameters of the magnetic field design of the two EPUs reduce the second-order harmonic contamination; the magnetic field is a quasi-periodic design for both the EPUs (Blomqvist 2010). Selected H blocks have a vertical offset δ. From the deflection and torque aspects, the δ increases the difficulty of the support structure design. Tables 1 and 2 show the mechanical parameters (Blomqvist 2006, 2010).

2. Mechanical layout

The whole EPU structure is shown in Figure 1. The frame is an assembly of structural steel weldments and aluminium components. The overall complexity of machining the mounting surface of guideways is reduced by producing the four major components (bottom frame, main upright, top frame and sub-upright) individually and then bolting them together. Each of the longitudinal connecting

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	Low-energy EPU	High-energy EPU
Magnet size (length × width × height) (mm)	45 × 30 × 15	13.5 × 30 × 30
Period (mm)	180	54
H block vertical offset δ (mm)	27.5[a]	8[a]
Minimum/maximum gap (mm)	21/300	12.5/150
Poles/magnets array length (mm)	43/3834	145/3905.5

TABLE 1. The main magnetic parameters
[a]The parameters are not finalized.

Model	Phase	Upper right			Upper left		
		F_x (kN)	F_y (kN)	F_z (kN)	F_x (KN)	F_y (KN)	F_z (KN)
HE EPU inclined	0	22	−27.5	0	−22	−27.5	0
	13.5	0	3	−3	6.2	−4	−41
	27	−34	20	0	34	20	0
LE EPU inclined	0	6.8	−4	0	−6.8	−4	0
	45	0.7	0.55	−0.7	1.8	−0.8	−3.6
	90	−9.2	2.4	0	9.2	2.4	0

TABLE 2. The most critical magnetic forces happen in the inclined polarization model

members are fabricated using 2024 aluminum beams or plates. This is a simple solution of matching the longitude thermal expansion of frame and girders. The main benefits are from avoiding a complicated girder guide system and locating the vertical guides closer to the girder to increase the stiffness of the structure and save space (Bahrdt 2006).

The whole structure is seated on bottom guides and driven by two separate ball screws, linear encoders, gearboxes and stepping motor systems. The system enables

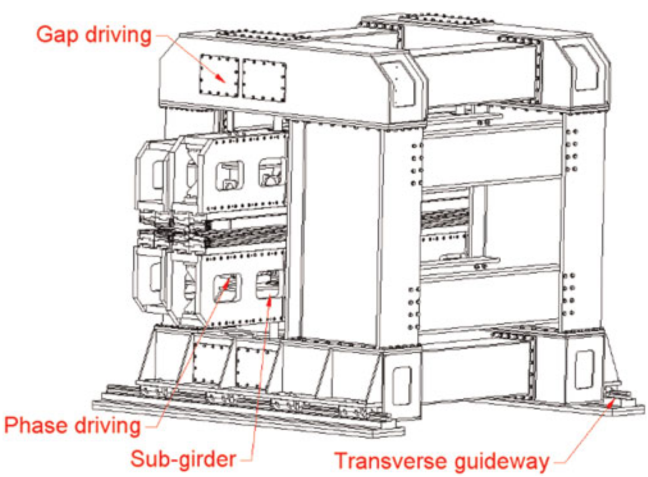

FIGURE 1. The EPU structure.

450 mm lateral movement for selecting the working EPU. Fine angle adjustment is possible if it is necessary.

The high-energy EPU and low-energy EPU use separate girders, so when one EPU is working, the other EPU can be opened to maximum gap to eliminate the magnetic field impact. Each girder has two separate vertical driving systems. Experience shows that even when the vertical guides are preloaded, the two sides of the girder are not necessarily driven completely synchronously. The girder position and taper can be adjusted by the separate driving systems and be monitored by the encoders. The drive components are installed inside the upper and bottom steel beams to meet spatial constraints.

Because of the huge 3D forces working on the girders and limited stiffness of the frame structure, the girders have lateral and roll deflections. To eliminate their impact on the vertical encoder reading, the gap encoders are placed at the two ends of the lower girder directly under the electrical beam. The actuator connects to the upper girder with ball joints (Bahrdt 2006; Bahrdt *et al*. 2008). Gap encoders, together with the lower girder position encoders, monitor and control vertical position and taper of the girders.

The lateral dimensions are a concern for the frames cantilever arm length. Keeping these dimensions as compact as possible, the phase driving systems are put inside the girder boxes. Because of the offset of the longitudinal magnetic force and the ball screw driving force, a large torque acts on the magnets stage and it will pass the torque to a certain portion of the linear bearings. The result is the magnet arrays will have an S-shaped vertical deflection and the linear bearing along with the screws will take large vertical forces. For reducing the effect, the phase driving nut bracket is made as long as possible.

The girders are designed as a bolted rectangular aluminium box to increase vertical stiffness and allow space for the phase drivers. Two sub-girders change the vertical support of the girder from two points to four points making the vertical deflection of the girders much more uniform.

Due to limited magnet accessibility, the magnet holders are carefully designed to accommodate and ease the shimming process. A wedge with a set screw and lock screw is used for vertical shimming; another set screw and lock screw can do lateral adjustments. Two types of magnet holders are designed to hold vertical and horizontal magnet blocks.

Other considerations in the design stage include transportation, installation and operation.

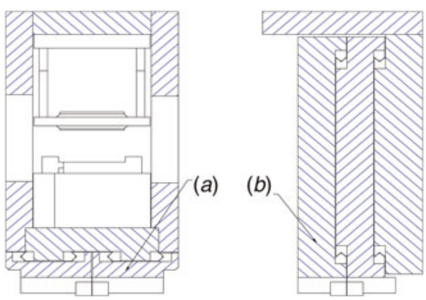

FIGURE 2. Two girder section options.

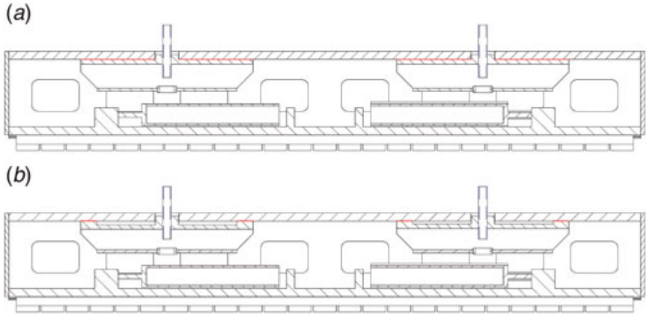

FIGURE 3. The two girder supporting options.

3. Finite-element analysis

The individual girders are modelled to optimize the girder structure. Horizontal stage girder (figure 2*a*) and vertical stages girder (figure 2*b*) are compared. Finite-element analysis (FEA) results show the former girder uses less material and gets larger stiffness. For this option, different wall thickness and window size are simulated to choose the best combination and control the maximum deflection is inside 30 μm. The sub-girders support the main girder that has two

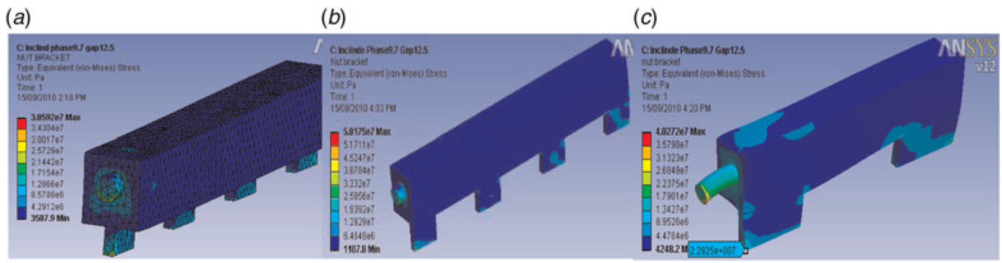

FIGURE 4. Stresses on three types of nut brackets.

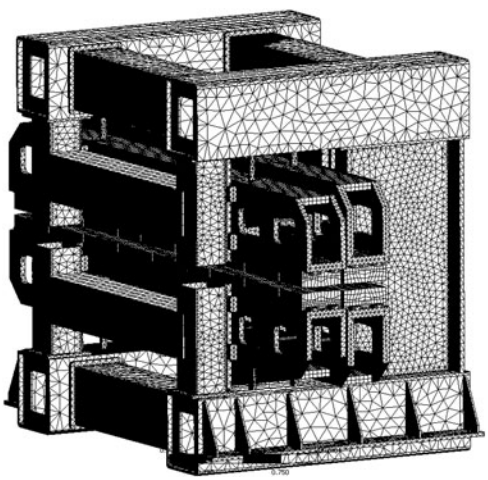

FIGURE 5. The whole structure of FEA model.

contacting options as shown in figure 3(*a*) and 3(*b*). FEA results show that option in figure 3(*b*) gets more uniform deflection. The sub-girder itself is simulated with many different wall thickness sets and, based on the FEA results, the proper wall thickness set was chosen. The phase shift driving nut bracket takes the key role in the girder deflection control. Different bracket shape, wall thickness and length scenarios are simulated. The structure and result are shown in figure 4(*a*–*c*). The nut bracket in figure 4(*b*) is 120 kg; the maximum stress on it is 58 MPa, while the nut bracket in figure 4(*c*) is 75 kg. The maximum stress on it is 40 MPa. The difference is obvious.

The model of the whole structure has 500 000 elements requiring long computation times to get the results (figure 5). It is used to optimize the frame structure and verify the final magnet array deflection.

4. Conclusion

A high-energy EPU and a low-energy EPU are being designed to share a single C style supporting structure. Each of the EPUs is 4 m in length. The design will be completed by the end of 2010 and will be fabricated and tested in 2011.

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